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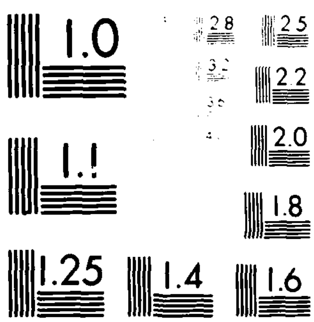

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FOREIGN TECHNOLOGY DIVISION

DESIGN OF THE LEADING EDGE OF A DELTA WING

by

Xu Dekang

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DESIGN OF THE LEADING EDGE OF A DELTA WING

by Xu Dekang

Foreign nations have already listed the "supersonic cruise fighter" whose major feature is large swept-back delta wings as one possible plan for the next generation of fighters. When cruising, the wave drag of the type of design is very small and it can also attain to subsonic maneuvering capabilities of very high overload by means of vortex lift. However, its shortcomings are that because the vortex flow produced causes a loss in leading edge suction which in turn brings about relatively high vortex drag, the maneuverability of the aircraft will be limited by a loss of engine thrust or excessively large fuel consumption (if an afterburner is used). The several leading edge designs introduced in this paper attempt to utilize many avenues such as regulating the leading edge's spanwise upwash distribution dividing the leading edge's three-dimensional flow into several two-dimensional flow fields, and using man-made separated vortex to delay the leading edge's air flow. This causes the flow field of this type of swept-back delta wing to still maintain attached flow characteristics with a very high angle of incidence whereupon it attains relatively large leading edge suction (decreased pressure drag). The principles and structures

of these designs are all relatively simple and very easily practically applied in aircraft design.

The Aerodynamic Characteristics of Blunt Leading Edge Large Swept-Back Delta Wings

In order to cause the air flow of the leading edge to not easily separate, a dome-shaped blunt leading edge must be used. Although it seems inappropriate for supersonic flight, yet because the leading edge's sweepback angle is very large, under general supersonic speeds, the leading edge is always located in the subsonic speed area behind the Mach cone. The supersonic cruise efficiency of the entire aircraft has higher demands than the pointed leading edge because the leading edge suction is relatively large. Yet, during subsonic large angle of incidence maneuvering flight, the vortex lift of the blunt leading edge is relatively weak and must maintain the leading edge's attached flow under a large angle of incidence so as to attain high lift. The increase lift measures which can be used on most swept-back wings, such as the slotted flap, cannot be applied here. On the one hand, the sweepback angle is too large and the three-dimensional flow which appears on the leading edge of the wing causes these measures to lose effectiveness; secondly, because the overload and dynamic pressure are very high at this time, there are many difficulties in the structure, weight and deformation of this type of mechanical design. Thus, we should study even simpler and more effective measures.

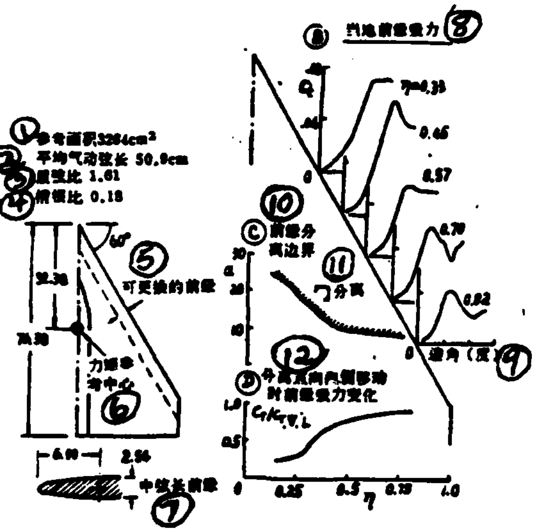

Fig. 1

Key: 1. Reference area 3264 cm^2
2. Average aerodynamic chord 50.9 cm
3. Span-chord ratio 1.61
4. Tip-root ratio 0.18
5. Changeable leading edge
6. Moment reference center
7. Middle chord leading edge
8. Local leading edge suction
9. Angle of incidence (degrees)
10. Leading edge's separated boundary
11. Separation
12. When the separation point shifts towards the inside, the leading edge's suction changes

Fig. 1 gives the basic parameters of a 60° swept-back delta wing with an elliptic arc blunt leading edge as well as the local leading edge suction coefficient characteristics of each spanwise position under different angles of incidence. η is the dimensionless coordinate of the spanwise position. The figure in

the middle right is the separation boundary joined by the corresponding angles of incidence that began to be separated from each spot on the leading edge. The figure in the lower right is the variational curve of the wing's leading edge total suction value during the process of shift from the wingtip to wing root when the separation points of the leading edge's air flow increase with the angle of incidence.

It can be seen from the upper figure that when the wingtip's leading edge air flow is a 10° angle of incidence it begins to separate, and when the wing root's leading edge air flow is a 20° angle of incidence, relatively large leading edge suction is still maintained.

It can be seen from the middle figure that in the spanwise range above the first half of the outer section, the separation boundary is completely flat. After being in an angle of incidence greater than 10°, the air flow of the leading edge separates very quickly and extends from the wingtip to the entire outer section. Yet, separation of the whole inner section only occurs above 20°.

It can be seen from the lower figure that the speed of the leading edge's suction loss caused by leading edge separation on the outer section of the wing is very slow. After the leading edge separation crossed the semi-span, leading edge suction dropped suddenly.

A very important conclusion can be drawn from the above characteristics. The designs for the leading edge of any type of

blunt leading edge delta wing only requires that the leading edge separation area of the outer section of the wing be controlled and not be allowed to extend passed the semi-span position. Only then can there be an effective decrease of the entire aircraft's drag when there is a large angle of incidence and maintenance of relatively large lift.

Small Fence on the Leading Edge

The fence is not a new concept for many aircraft use it to delay wing stall and to raise maximum lift. Yet, it can also act as a measure for decreasing drag when an aircraft has a large angle of incidence. This, however, has not received much attention. Actually, after a small fence is installed on the leading edge of a large swept-back delta wing, because of its partial reflector plate effect, the very large constant pressure line of the sweepback angle on the wing is forced to lose the sweepback in the vicinity of this position. As a result, an opposite effect is produced on both sides of the fence. The leading edge suction peak and adverse pressure gradient on the outer side of the wing are alleviated which is equivalent to enlarging the curve of the leading edge and thus stall is delayed; for the inner side of the wing, this is equivalent to shrinking the curve of the leading edge. Yet, because the entire upwash in the inner side area is quite small, its effect on the flow field is also very small. Adding the effect of the small fence itself blocking the leading edge's boundary layer and piling up towards

the outer side effectively controls the leading edge's flow field on the outer side of the wing.

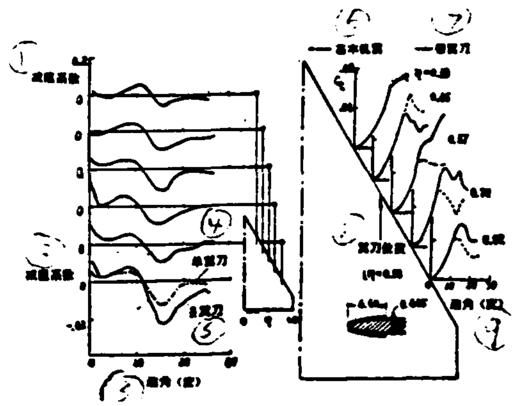

Fig. 2

Key: 1. Decreased drag coefficient
2. Decreased drag coefficient
3. Angle of incidence (degrees)
4. Single fence
5. 3 fences
6. --- Basic wing
7. —— Fence
8. Fence position
9. Angle of incidence (degrees)

Fig. 2 gives the results of wind tunnel tests. The figure on the left shows the effects of different positions and different quantity small fences on decreasing drag. The figure on the right shows the changes of the leading edge suction along the spanwise after arranging a small fence in the semi-span area.

It can be known from the figure on the left that the effect of the small fence on its spanwise position is very sensitive and when placed in the semi-span area the effects are optimal. Furthermore, when three small fences are used, the decreased

drag effects are even better and moreover the effect range of the angle of incidence can be even larger. It can be known from the figure on the right that after a small fence is added to the leading edge, although the inner side of the wing only has very slight changes in the flow field nearest the fence area, yet the flow fields of the entire outer side all show large improvement.

Chordwise Slot

Mechanism research has pointed out that the three-dimensional effect of swept-back leading edges can separate the leading edge into several two-dimensional sections which are used to weaken and delay the stalled angle of incidence. If a small slot opens along the chordwise in a certain area of the delta wing's leading edge causing the formation of an air bottle when the frontal surface air flow passes a small slot, the leading edge's flow field is divided into two sections which can cause an effect equivalent to that of a small fence.

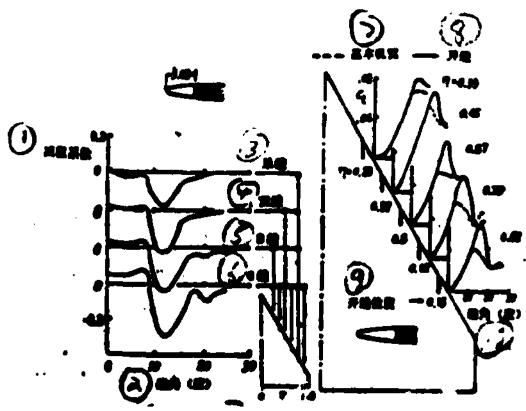

Fig. 3

Key: 1. Decreased drag coefficient
2. Angle of incidence (degrees)
3. Single slot
4. Double slot
5. 3 slots
6. 5 slots
7. --- Basic wing
8. —— Slot
9. Slot position
10. Angle of incidence (degrees)

The left figure in fig. 3 shows the effects of slot position and slot number on decreasing drag. The more slots there are the better the effect of decreasing drag. Yet, when in a small angle of incidence, there is the opposite effect. This is mainly the effect of the frontal drag of the slot's end surface. If the inner side of the end surface is made into a round and smooth streamline, this partial drag can also greatly decrease. The right figure in fig. 3 shows the spanwise changes of the leading edge's suction after 5 small slots are opened. At the same time, the suction characteristics of all of the positions of the leading edge are improved and moreover they all seem to have simultaneous stall when in a 20° angle of incidence. This shows that the three-dimensional flow of the entire swept-back wing has already been divided into several analogous two-dimensional flows.

Vortex Produced Blade Under Leading Edge of Wing

A vortex produced blade is generally fitted on the surface of the wing and is used to solve unforeseen separation problems. A vortex blade installed in a certain place under the leading

edge of a wing uses the induced effect of the vortex produced by the air flowing around it on the nearby leading edge flow field. This not only changes the spanwise distribution of the area's nearby leading edge upwash (the inner side upwash increases and the outer side upwash decreases), but also delays separation on the outer side of the wing. At the same time, it also prevents the boundary layer from accumulating from the inner side to the outer side and effectively controls the flow field of the outer section of the wing.

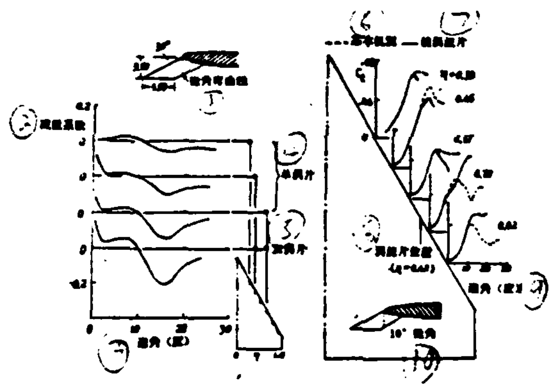

Fig. 4

Key:
1. Downstroke angle curve
2. Decreased drag coefficient
3. Angle of incidence (degrees)
4. Single vortex blade
5. Double vortex blade
6. --- Basic wing
7. —— Installed with vortex blade
8. Vortex blade position
9. Angle of incidence (degrees)
10. Downstroke angle

The left figure in fig. 4 shows the effect of the position and quantity of vortex blades on drag decrease. The right figure

shows the changes of the leading edge suction along the spanwise after a vortex blade is placed in a 62% semi-span length position area. Because the vortex blade can produce a certain outward deformation under the vortex effect, the vortex plate should also have a small inward downstroke angle.

It can be seen from the figure on the left that similar to the small fence, when the vortex blade is placed in a 50-62% semi-span length area, the results are best. The two vortex blades can further raise effectiveness, and naturally, when the angle of incidence is small, the drag can increase. It can be seen from the figure on the right that although the flow field of the inner side of the wing has some deteriorating, yet when the suction of the inner side of the leading edge begins to drop, the leading edge suction of the entire outer side of the wing continuously increases and extends to a very large angle of incidence.

Spanwise Vortex Plate Under Leading Edge of Wing

A very narrow thin plate is fitted along the spanwise of the wing surface under the leading edge causing the leading edge flow to flow around the sharp edge of this plate and produce a spanwise vortex. Because of the large sweepback effect, this spanwise vortex is stable and continuous. This seems to run counter to the previously mentioned demands to maintain the goal of a leading edge attached flow under a large angle of incidence. Yet, in reality, it is only necessary that the measurements

for the thin plate be appropriately selected. This can control the size and position of the spanwise vortex and cause it to be just in front of the leading edge. On the one hand, this produced suction supplements the leading edge suction. On the other hand, it causes the rear surface's incoming flow when under the effects of vortex rotation and even when there is a large angle of incidence, to be able to have the upper wing surface of the wing's leading edge maintain attached flow. This improves the characteristics of the large angle of incidence.

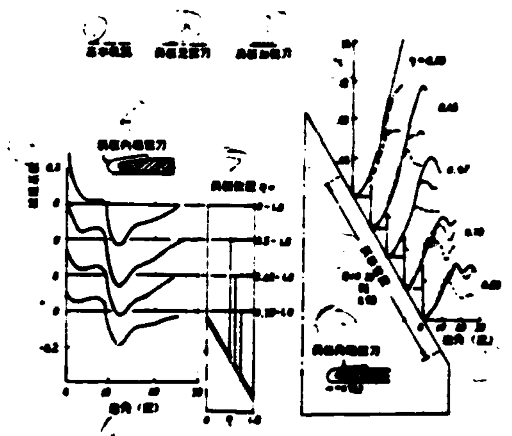

Fig. 5

Key:
1. --- Basic wing
2. —— - —— Vortex plate without fence
3. —— Vortex plate with fence added
4. Decreased drag coefficient
5. Angle of incidence (degrees)
6. End fence in vortex plate
7. Vortex plate position
8. Vortex plate position
9. Angle of incidence (degrees)
10. End fence in vortex plate

The figure on the left of fig. 5 shows the effects of different length vortex plates on drag decreases. To inhibit the disturbance of the inner section leading edge flow field on the vortex, a leading edge small fence is added to the inside end of the vortex plate. The figure on the right is the spanwise distribution of the leading edge suction after a vortex plate has been installed.

From the figure on the left it can be seen that the vortex plate only needs to be installed in a η =0.5 to 1.0 area on the outer side of the wing. Its effect is actually equivalent to an entire wingspan vortex plate and the effect of the length of the shortened vortex plate also shrinks in accordance with it. In spite of this, even if it only has a $\frac{1}{4}$ wingspan outer side vortex plate, its decreased drag effect is still quite noticeable.

From the figure on the right it can be seen that the leading edge suction increments attained by adding a small fence on the vortex plate are larger than any of the aforementioned plans.

The Effects of Four Designs on the Longitudinal Stability of a Wing

After a large swept-back delta wing shows separation vortex of the leading edge, due to the effects of vortex lift, the aerodynamic center shifts forward to the center of gravity of the whole aircraft and this causes an unstable moment on the wing. After using any of the above mentioned leading edge designs, the delay of the leading edge's air flow separation effectively

maintained the leading edge suction located in the rear surface of the center of gravity on the outer side of the wing. This greatly improved the stability of the entire aircraft.

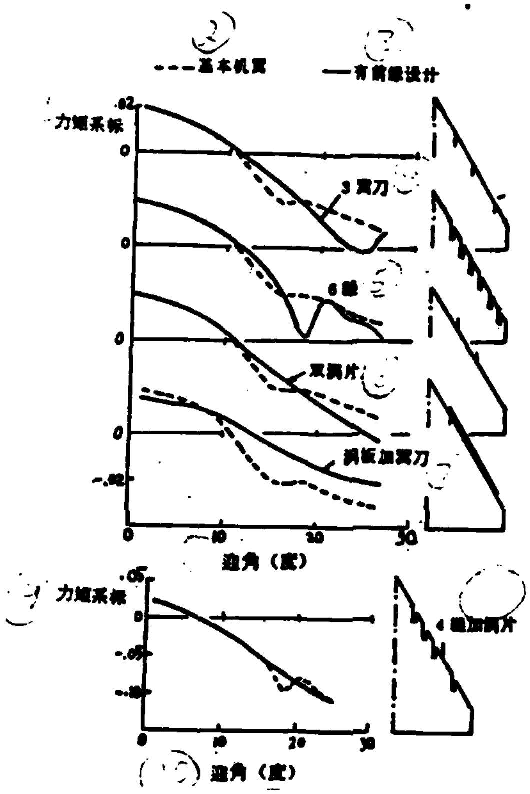

Fig. 6

Key: 1. Moment coefficient
2. --- Basic wing
3. —— With leading edge design
4. 3 fences
5. 6 slots
6. Double vortex blade
7. Vortex plate with fences added
8. Angle of incidence (degrees)
9. Moment coefficient
10. Angle of incidence (degrees)
11. 4 slots with vortex blade added

Fig. 6 shows the separate effects of four types of designs on the longitudinal stability of a wing. In this way, it can be

seen that the small fence and chordwise slot can increase the stability range of the angle of incidence for a wing and the chordwise vortex blade and spanwise vortex plate will completely eliminate the unstable area. The lower figure in fig. 6 gives an example of the joint utilization of the slot with a vortex blade added. The moment characteristics change with complete linearity.

Conclusion

Wind tunnel tests have proven that for a large swept-back blunt leading edge it is only necessary to control the leading edges' flow field on the outer side of the wing. Then, excellent large angle of incidence, high lift and low drag characteristics can be attained. For this reason, the four designs proposed for the leading edge all possess structures that are simple, effects which are noticeable and at the same time can also improve the longitudinal stability of a wing. The shortcoming is that when the angle of incidence is small all of them require added drag, especially the spanwise vortex plate which showed the best results with a large angle of incidence and decreased drag. In a secondary position was the vortex produced blade where the drag of the small angle of incidence was somewhat larger. Yet, in actual use, it is easy to make their designs acceptable so that these types of delta wing supersonic cruise fighters can maintain relatively low drag in the entire angle of incidence range.

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